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ADVANCE REPORT

on the

SEDIMENTATION SURVEY OF HAYES LAKE
HAYES, SOUTH DAKOTA

June 8-15, 1937

by

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In Cooperation With

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Sedimentation Studies
Division of Research
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ADVANCE REPORT ON THE SEDIMENTATION SURVEY OF HAYES LAKE HAYES, SOUTH DAKOTA

GENERAL INFORMATION

Location (fig. 1).

State.--South Dakota.

County.--Stanley; sec. 29, T. 5 N., R. 26 E.

Distance and direction from nearest city.--At Hayes, S. Dak., 37 miles west of Pierre, S. Dak.

Drainage and backwater.--Frozenman Creek, a small intermittent stream which flows generally southeastward to join the Bad River approximately 20 miles southwest of Fort Pierre, S. Dak.

Ownership. State Game and Fish Department of South Dakota.

Purpose served. Recreation.

Description of dam. The dam is a gravity-type earth-fill structure 28 feet in height above the original stream channel and 530 feet long. Its top width is 14 feet, its upstream slope 3:1, and its downstream slope $1\frac{1}{2}$:1. The dam has a northwest trend and is located just below a sharp bend and immediately above the junction of two small arroyos which enter the main valley from the east and the west.

The main spillway, excavated through a saddle into the east arroyo, is 6 feet lower than the top of the dam, or 22 feet above the stream channel. The auxiliary or flood spillway, which drains into the west arroyo, is 3 feet lower than the top of the dam and has an approximate width of 90 feet. As originally constructed the main spillway was approximately 20 feet in width and had no perceptible grade for 375 feet beyond the reservoir basin. At this distance a sharp drop of 12 feet in a distance of 10 feet led the overflow into the east arroyo. This spillway, excavated in heavy clay subsoil

Figure I

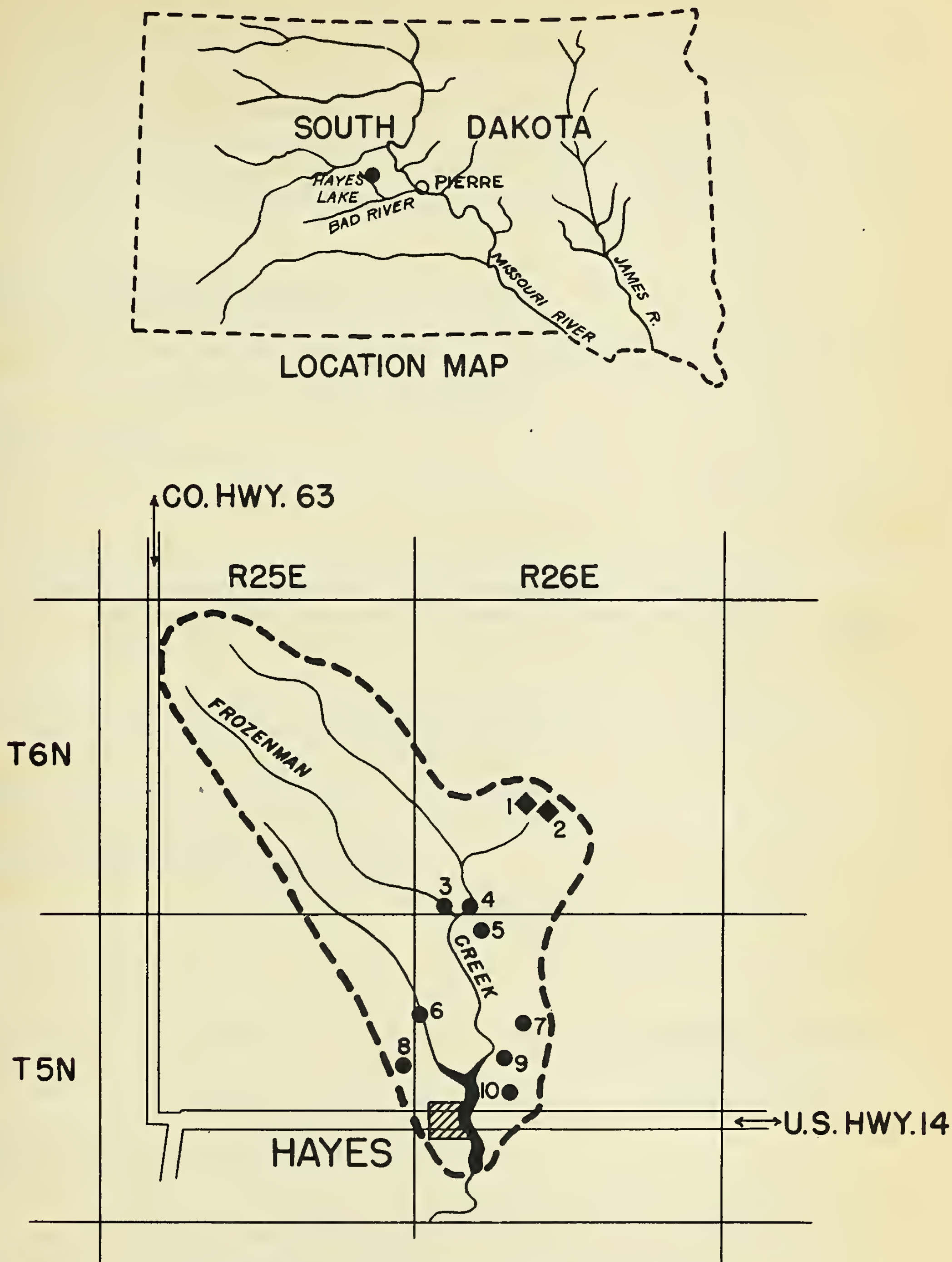

FIG. I LOCATION AND GENERAL RELATIONS OF HAYES LAKE AND ITS DRAINAGE BASIN

- - - WATERSHED BOUNDARY
● STOCK PONDS
■ STOCK PONDS SURVEYED

0 1 2 3 4 5 6
SCALE IN MILES

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and protected at the lower end only by a mat of willow branches, has proved inadequate to carry the occasional flood flows coming down the stream. Plans for the construction of a concrete spillway to replace the existing one specify a spillway crest at 89.0 feet (local datum) or 25 feet above the original stream channel. Spillway elevation of 89.0 feet on the local datum used in this survey corresponds to an elevation of 1,955.865 feet above mean sea level (U.S. C. & G.S. datum).

Date of completion of dam. March 1933.

Date of sedimentation survey: June 1937. Age of reservoir at date of survey: 4.2 years.

Length of lake.

	Miles
Basin proper	1.15
Ponded channel (between lake proper and upper limit of backwater)	1.39
Total	2.54

There has been no change in the length of the lake at crest stage since the dam was constructed.

Area of lake at crest stage. 88.1 acres.

Storage capacity to crest level.

	Acre-feet	
Original	629	(204,959,650 gals.)
At date of survey	580	(188,993,000 gals.)
Loss due to silting	49	(15,966,650 gals.)

General character of reservoir basin.

Hayes Lake occupies a somewhat sinuous stretch of the valley through which Frozenman Creek meandered on a poorly developed narrow flood plain. (See fig. 2.) This flood plain is locally absent but is as much as 200 feet wide on the inside of some bends. Its surface has a general elevation of 8 to 10 feet above the channel bottom. Above the flood plain are local and disconnected remnants of higher

stream terraces, but only in a few places does the impounded water encroach on their very gentle slopes.

The submerged stream channel ranges in width from 15 to 20 feet and in depth from 4 to 12 feet. Since the stream is intermittent the channel tends to be poorly defined, although locally the stream has gouged deep holes into the clay subsoil. The average original gradient was 6.5 feet per mile through the ponded channel section, and 8.5 feet per mile through the basin proper.

The lake has an average width of 400 feet in the basin proper, although it widens to 750 feet approximately 0.9 mile above the dam, where a tributary stream, separated by a low submerged divide, flowed approximately parallel to the main stream for a distance of about 1,400 feet. The ponded channel section has an average width of approximately 100 feet in the lower part and narrows very gradually to normal stream width of 15 to 20 feet near the head of backwater.

Area of drainage basin. 40 square miles as determined by the State Game and Fish Department.

General character of drainage basin.

Geology.--The drainage basin lies entirely within the outcrop area of the Pierre shale of Upper Cretaceous age. This formation consists of 1,000 feet or more of dark-gray shales, mostly soft and relatively uniform in composition, which lie nearly horizontal in this area. Locally, the Pierre in this region is overlain by isolated remnants of a former blanket of sands, gravels, and clays of late Tertiary age.[1] However, as only one small outcrop of these deposits was noted in the Hayes basin, they probably have had only a minor part in erosion and sedimentation. Occasional exposures of the Pierre in the area reveal a laminated, well-jointed soft shale, generally of a dark slate-blue color, although in some exposures it is almost black and in others very light gray. Concretions and lenses of fibrous calcite and of iron carbonate are distributed widely through the exposures. The shale, on weathering, tends to assume a dark-brown to gray color, and much of it disintegrates into tiny soft pellets which subsequently form a heavy clay subsoil.

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[1] Darton, N. H. Preliminary report on the geology and underground water resources of the central Great Plains. U. S. Geol. Survey Prof. Paper 32: 168, 1905.

The late Tertiary (?) deposit consists predominantly of a heavy almost black sandy clay which contains many lenses of medium sand locally merging into coarse partially cemented stream gravel.

Topography and drainage.--The watershed area in general is moderately to gently rolling but includes large areas of almost flat uplands at divergent elevations. The divide, especially that part separating the area from the Cheyenne River drainage basin to the north, is so gentle and undulatory that it is difficult to trace in the field. The main valley of Frozenman Creek above the lake has a generally rounded cross section although it is locally flat-bottomed. The valley bottom is about 100 feet below the general level of the uplands in the immediate vicinity of the lake and averages approximately 1,000 feet in width. The valley sides are generally moderately sloping, although slopes as high as 56° occur along the lower 3 miles of the main valley and adjacent to the lake.

The drainage is intermittent; the streams flow only in the spring after the snow melts and occasionally for several days at a time after summer rains. Run-off tends to be "flashy", owing in considerable part to the impermeable nature of the soil. Deep "gouge holes" in the stream channels, scoured by heavy discharge, are common. Many of these "gouge holes" retain water for long periods after rains and serve as water holes for range stock.

Soils.--The reconnaissance soil survey of western South Dakota[2] shows the drainage basin to lie entirely on the Pierre clay series. This series (undifferentiated in the survey) includes soil types ranging in texture from silty clay loam through silty clay to heavy clay. Of these types the clay predominates.

The most distinguishing characteristic of the Pierre clays is their heavy, sticky nature, which has caused them to be locally termed "gumbo". Three color types of topsoil are distinguishable in the area, namely, a light grayish-brown soil, a yellowish-brown soil, and a dark-brown soil that is almost black.

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[2]Coffey, George N., and party, Reconnaissance soil survey of western South Dakota, U. S. Dept. Agr., Bur. Soils Field Oper. 1909, Rept. 11:1432, 1912.

The subsoil, which occurs at a depth of 6 to 10 inches, is usually a heavy gray to yellowish-brown clay. In some areas it is almost black. Soft shale is usually found 3 to 6 feet below the surface.

The soil has a pronounced tendency to swell and is difficult to cultivate after wetting. Upon drying, the heavy clay soil in particular is likely to crack and granulate. In some cases cracks may extend to a depth of several feet. In plowed fields the tendency to granulate upon rapid drying results in the formation of a thin surface coating of loose soil which is unusually susceptible to both wind and water erosion.

Erosion conditions.--Erosion by both water and wind occurs in the drainage area. Except for the previously mentioned "gouge holes" in the stream channels, water erosion occurs mainly in cultivated fields and on the steep valley slopes, where sheet erosion is locally quite severe. Over most of the open range land, however, sheet erosion is slight.

Slight wind erosion has occurred over the entire upland area, as shown by the many bare "blow-outs". Wind erosion has done considerable damage on the upland to exposed cultivated fields, many of which are wind-furrowed and cut down to bare subsoil. Drifts 3 inches to 3 feet in height are common along fence lines of such fields, and filled road ditches and other drainageways are common. These drifts wash readily during rains and may account for a large part of the sediment that goes directly to the lake.

Water and wind erosion in the basin have been supplemented by minor mass movements of the soil on the steeper valley slopes near the lake. This slumping has produced an irregular, step-like profile and broken up the soil, thus facilitating sheet erosion.

It seems likely that the drought of the past few years, accompanied by a decrease in vegetative cover, has probably accelerated the erosion rate. The present condition, so far as could be ascertained, has probably prevailed throughout the short history of the lake.

Land use and vegetative cover.--Accurate figures on land use in the drainage area are not available. From observations made during the course of the survey it is estimated that approximately 85 percent of the area is open range used for

grazing by both cattle and horses. Of this amount approximately 15 percent appears to be abandoned homestead land which is reverting to range conditions. Ten percent of the drainage area is devoted to cultivation of small grains, of which wheat, oats, and flax are the principal crops. Only about 5 percent of the total area is devoted to open-growing crops, predominantly corn and cane.

The normal cover of the range is a rather dense short-grass type, principally buffalo and grama grass, through which is evenly scattered a growth of taller western wheat grass.[3] In normal years this cover furnishes a good quantity and quality of "wild hay" and forms an excellent protective cover. However, in the past four years (i.e., during the entire life of the lake) precipitation has been markedly deficient and there has been comparatively little corresponding reduction in grazing. As a result, the natural cover has been badly depleted, leaving the soil unusually lacking in protection against accelerated erosion. During this period the cover has consisted mainly of parched or dead grass with a scattering of hardy weeds and alkali grass. During the course of the survey, however, heavy rains resulted in a luxuriant growth of weeds, beneath which cover the revived normal grasses began to reappear. The present cover (June 1937) consists mainly of wild sunflowers, pepper grass, and alkali grass growing thickly enough to provide relatively good protection against erosion.

Mean annual rainfall. The normal precipitation of this area is 16.99 inches.[4] During the history of the lake (1933-37), however precipitation was consistently below normal, as shown by table 1.

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[3]Shantz, H. L. The natural vegetation of the United States. Atlas of Amer. Agr., U. S. Dept. Agr. p. 19, 1936.

[4]Climatological data, 1890-1937. South Dakota Section, U. S. Dept. Agr. Weather Bureau.

Table 1.--Rainfall record, 1933-1937

Year	Annual rainfall	Departure from normal
	Inches	Inches
1933................................	13.29	-3.72
1934................................	11.04	-5.97
1935................................	13.09	-3.92
1936................................	6.53	-10.29
1937................................	1/	1/

[1]Records to August seem to indicate that rainfall may approach normal (at least for summer months).

Approximately 56 percent of the average annual rainfall occurs during the period May to August inclusive. Rainfall during the past 4 years has been concentrated in the summer months.

These rainfall measurements were made at the cooperative Weather Bureau Station at Hopewell, S. Dak., approximately 8 miles northeast of Hayes.

Discharge data. An approximate maximum discharge of 1,573 cubic feet per second, or nearly 40 second-feet per square mile of drainage area, was measured at the dam on June 13, 1937 after a rainfall of approximately 1.50 inches on June 12 and of 0.50 inch on June 13. No further figures on run-off or average discharge for Frozenman Creek are available.

Evaporation. Records of three Weather Bureau stations in the general vicinity show that approximately 33 inches of evaporation takes place during the 6-month period April to September.

HISTORY OF SURVEY

The survey of Hayes Lake and its drainage basin was made during the period June 8 to June 25, 1937. Of this period June 9 to June 17 was devoted to the lake survey and the remainder of the time to the drainage area study, including the detailed survey of two stock ponds and reconnaissance examination of eight others (table 3, p. 17). The survey was made by a field party of the Section of Sedimentation Studies, Division of Research, Soil Conservation Service. Members of the party were Leland H. Barnes, chief, Mark P. Connaughton, geologist, Alvin T. Talley, Alfred J. Kjarsgaard, Robert M. Dill, and Richard K. Frevert. General arrangements for the survey, including a reconnaissance of the lake and examination of the drainage basin, were made by Louis M. Glymph, Jr. F. L. Duley, field representative of the Research Division, Soil Conservation Service, was instrumental in making arrangements and securing cooperation for these studies.

The Soil Conservation Service acknowledges the generous cooperation of the Engineering Department of the Works Progress Administration district office at Pierre, S. Dak., through whose courtesy base maps and plans for the proposed spillway improvements were made available. Acknowledgment is also due to O. H. Johnson, of the State Game and Fish Department, for his valuable assistance in furnishing details on the original construction. Milt Elkins furnished helpful information on conditions in the drainage basin and aided materially in the detailed survey of the two stock ponds on his ranch.

Field work began with the chaining of an 830-foot base line across the top of the dam. From this line a triangulation net of 14 stations was established with plane table and alidade. As a check a secondary base line 900 feet in length was chained along the north shoulder of U. S. Highway No. 14 between triangulation stations 1013 and 1014 (fig. 2). This triangulation network was supplemented by 5 stations established by a stadia traverse to the head of backwater.

The entire crest-level shore line, 6.59 miles in length, was mapped on a scale of 1 inch to 200 feet. As the lake was consistently below crest during the survey, plane-table mapping of the shore line was supplemented by spirit-level control, particularly in those portions of the lake where the water surface intersects gentle slopes.

Original and remaining reservoir capacities and silt volumes were determined by the range method of survey.[5] A total of 21 ranges was established, sounded, and spudded. A transit was used for keeping the boat on line during sounding and spudding operations. All range ends, cut-in stations, and the base-line stations were permanently marked by numbered iron pipe set in concrete.

On June 12 and 13, during the survey, an unusually heavy rainfall and subsequent heavy run-off caused the deposition of a measurable amount of new silt in the reservoir. As the newly deposited silt was quite distinct from the old silt, accurate measurement was made of the amount of sediment deposited during one short period of heavy run-off. The results of this study are included in this report.

Three samples of the old sediment and one sample of the newly deposited material were collected for determination of volume-weight relations. Preliminary determinations were made by the hydraulic laboratory unit of the Section of Soil and Water Conservation Experiment Stations, Division of Research, in Washington, D. C.

Two stock ponds in the drainage basin were mapped with plane table and alidade on a scale of 1 inch to 100 feet, and the original and remaining capacities and silt volumes were determined by the contour method of survey.[6]

Watershed and land-use boundaries of the stock-pond drainage areas were mapped by a transit survey.

A capacity curve (fig. 3) showing water storage at the time of the survey was prepared by means of 2-foot contours of the basin drawn from sounding data.

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[5]Eakin, Henry M., Silting of reservoirs. U. S. Dept. Agr. Tech. Bull. 524: 129-135, 1936.
[6]See footnote 5 (pp. 135-136).

SEDIMENT DEPOSITS

Character of Sediment

The sediment of Hayes Lake can be separated into three phases: (1) old stream-borne sediments (those deposited prior to the extensive deposition of June 12-13, 1937), (2) new stream-borne sediment (deposited during the June flood flow), and (3) off-shore sediment.

Old sediment.

The old sediment consists of only slightly compacted silt and silty clay ranging in color from bluish gray to deep black. The texture is remarkably uniform throughout.

In view of the uniform character of the sediment and the lack of coarse grains in that portion derived from the drainage basin proper, it is illuminating to note the mechanical composition of the Pierre clay series as presented in table 2.

Table 2.--Mechanical analyses of Pierre clays[1]

Description	Fine Gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Soil.........	0.1	0.8	3.0	8.9	6.4	44.8	35.8
Subsoil.....	.1	.9	3.3	8.6	7.7	42.6	36.7

[1]See footnote 2 on page 4 (p. 1433).

Field examination failed to reveal the usual tendency toward concentration of coarser sediment near the head of the lake. The old sediment is readily distinguishable from pre-lake material underlying it because, never having been exposed to drying since deposition, it is poorly compacted and lacks the tenacious quality of the old soil.

Locally the silt has a rather high organic content. Occasional zones of deep black, highly carbonaceous sediment were

penetrated in various parts of the lake. In all cases the organic material is very fine in texture, consisting of small stems, grass blades, seeds, and like materials.

In spite of the intermittent nature of silt deposition in the lake, no apparent tendency toward banding or lamination of sediment was noted in the field examination.

New sediment.

The silt deposited after the heavy rains of June 12-13, 1937, was characterized by a much lighter color than the old sediment and by a very low degree of compaction at the time of the survey. The color ranged from yellowish gray in the upper part of the lake to light yellowish brown in the lower part. This silt was so poorly compacted, or "soupy", that gentle handling of the spud was necessary to prevent it from washing out of the cups before the spud could be pulled to the surface of the water.

Off-shore deposits.

The predominantly light-brown littoral deposits derived from wave and sheet erosion of the steeper banks in the lower part of the lake are quite distinct from the strikingly uniform silt brought down by the main stream. They consist of sandy silt with many rounded clay pellets such as occur immediately above the weathered bedrock of the Pierre clay in the wave-cut exposures along the lake shore. The sandy texture of the sediment is due to inclusion of small, angular grains derived from wave-cutting of the weathered calcite veins and concretions which are exposed in considerable numbers in the wave-cut banks.

Volume-weight relations.

Determinations of the dry weights of three samples of the old sediment and one sample of the new material gave an average weight of 41.7 pounds per cubic foot for the old more compact silt, and 32.7 pounds per cubic foot for that deposited by the flood of June 12-13, 1937.

Distribution of Sediment

The general distribution of silt, characterized by comparative irregularity in thickness, appears to be governed principally by two factors: (1) The action of currents, maintained during heavy inflow because of the channel-like configuration of the reservoir, tends to keep constricted areas on the outside of bends

fairly clear of sediment, and at the same time to deposit sediment in relatively straight stretches and on the inside of bends. (2) The irregularity of the pre-lake stream profile, due to the numerous "gouge holes", favors comparatively greater accumulation in restricted areas.

Two profiles, one (fig. 4) showing maximum water and silt depths along the thalweg of the original stream channel, and the other (fig. 5) showing average water and silt depths on all ranges crossing the main stream, depict the longitudinal distribution of sediment. As shown in figure 4, the trend of silt distribution within the old channel is toward the establishment of a uniformly sloping, smooth bottom gradient throughout the length of the lake. This trend has resulted in a thickening of the sediment blanket over low areas in the original stream channel and a corresponding thinning over the high areas. The comparatively regular thickness of the new sediment blanket resulting from the flood of June 1937 would seem to indicate that this process had affected at least approximate equilibrium in the profile prior to this stage of deposition. The noticeable decrease in the thickness of the old sediment on range R33-R32 (approximately 9,800 feet above the dam) is believed to be due to the scouring action of currents during the flood flow.

Figure 5 indicates a comparatively constant average thickness of old silt throughout the lake as a whole, with but a slight tendency toward greater concentration in the lower reaches. On the other hand, the new sediment resulting from the flood flow of June 12-13 is much more important volumetrically in the upper segments of the lake, roughly, from range R12-R13 to the head of backwater. A study of the cross sections of the ranges confirms this feature, for below range R12-R13 the new silt is confined essentially to the old channel, whereas above this range it is evenly spread over the submerged flood plains as well as the channel.

However, inasmuch as the measurements on which both figure 5 and the cross sections are based were made within several days after the flood flow of June 12-13, it is probable that complete settling of the suspended load had not taken place in the deeper parts of the lake, essentially below range R12-R13. If this is so, the present distribution of the new silt is misleading. In the absence of data on the concentration of suspended silt particles within the reservoir during this period, it is impossible to evaluate this factor.

In addition to marking the dividing line between the deep and the comparatively shallow parts of the lake, range R12-R13 also marks the lower end of an exceptionally wide section which begins

at range R18-R19. If we accept the distribution of new silt shown in figure 5 as a true picture, it seems evident that this wider basin has functioned in some degree as a silt trap for the period of sedimentation following the June 1937 flood.

The absence of a decrease in average thickness of the old silt below range R12-R13, similar to that noted in the new silt, is no doubt due in part to the fact that the old silt, as plotted in figure 5, includes the wave-eroded material, which was confined essentially to the lower reaches of the lake.

The maximum thickness of sediment on any cross section occurs in the old stream channel. The thickness in the channel ranges from 1 to 5 feet, whereas the silt blanket over the old flood plain never exceeds 0.5 foot.

On range R1-R2, (fig. 2) 650 feet above the dam, the maximum thickness in the channel is 3.2 feet and the average on the flood plain is less than 0.1 foot, whereas on range R1-R4, 1,270 feet above the dam, the maximum channel deposition has been only 1.6 feet and the average silt depth on the flood plain is 0.2 foot. On this latter range, which crosses a high point of the original stream profile, there is evidence of intensive current action during high water stages.

On range R5-R6, which is 1,850 feet above the dam and apparently crosses one of the old "gouge holes", the greatest water and silt depths found in the entire lake were measured. Here 4.8 feet of sediment has accumulated in the channel and 0.4 foot on the flood plain. From this range upstream the silt thickness in the channel gradually decreases to 2.0 feet on range R18-R20, which marks the lower end of the narrow ponded channel. From this point onward the silt depth in the channel averages about 1 foot up to range R35-R34, beyond which little permanent deposition has taken place. Above range R5-R6 the silt thickness on the flood plain averages 0.4 foot very consistently.

Current action in Hayes Lake.

On several ranges which had been measured both before and after the flood flow of June 1937 it was found that locally the old silt had been scoured out and new silt deposited in its place. This scouring action was confined to the original channel and did not affect the submerged flood plain. On range R23-R24, in the ponded-channel section of the lake, several tenths of a foot of the old silt was scoured out and replaced by new sediment. This action was confined to water depths of 10 to 11 feet over the original stream channel. On range R26-R25, on a bend just above

range R23-R24, 0.2 to 0.6 foot of old material had been replaced by new sediment. Here the action was confined to water depths of 6.5 to 9.3 feet over the original stream channel. However, on range R27-R28, just below a bend, no appreciable change was noted in the original stream channel at a depth of 7.6 feet, but at depths of 6 to 6.5 feet, 0.1 to 0.2 foot of silt was scoured out. On range R31-R30 almost within but slightly upstream from a sharp bend, no scouring had taken place at the greatest depth of 5.9 feet, although 0.2 to 0.3 foot was scoured out at depths of 4.5 to 6 feet.

The profile drawn along the original stream channel (fig. 4) indicates that considerable scouring has also occurred on range R33-R32, which is also on a sharp bend; the magnitude of this scouring, however, was not measured. On the other hand, measurements on range R31-R29, at the mouth of the main tributary arm, show no perceptible scour.

These observations, although incomplete, bring out several conclusions which may apply to current action within small channel-type reservoirs in general. First, the current in this reservoir tends to follow closely the pre-lake stream channel. Secondly, bottom scouring on bends and deposition in straighter segments seem to follow closely the trend of normal river behavior. Thirdly, the effect of such current action is measurable at least 10 to 11 feet below crest level; however, since the flood crest in this part of the lake reached 5 feet above lake crest, the actual water depth during the time of scouring may have approached 15 to 16 feet.

Figure 4 also shows that the old silt blanket within the old channel is notably thicker in the lower parts of the lake. It seems not unlikely that one of the important factors contributing to this increased thickness is current action, concentrated along the original stream channel, which has continued even down to these segments.

Origin of Sediment

Wave erosion, aided by severe rill and sheet wash on the steeper slopes adjacent to the lake, has contributed an appreciable quantity of sediment to the lake. This shore wash is distributed in comparatively narrow zones below crest level adjacent to the wave-cut areas. These zones average about 30 feet wide but locally attain widths of as much as 60 feet. Although no specific measurements of this feature were made, an approximate check indicates that a minimum of 2.6 acre-feet, or more than 5 percent of the total reservoir sediment, originated in this manner. While this proportion is somewhat high compared with lakes in other regions,

it should be recalled that stream flow is intermittent, whereas wave action against the easily washed soils and weak shales is almost constant.

Of the total volume of 49 acre-feet of sediment, 15.7 acre-feet, or 32 percent, was deposited by the flood following the intense rainfall of June 1937. To account for this large percentage of the total sediment deposited in one very short period, it is necessary to recall the rather abnormal history of the lake. The entire period has been featured by drought or near-drought conditions, as indicated in table 1 (p. 7). During this time the lake had only twice discharged overflow water through the spillway. Neither of these previous overflows were comparable to the heavy discharge of June 1937. In short, during the four years of its life up to June 12, 1937, deposition of sediment occurred only infrequently and in no great amount, because the stream itself flowed only rarely.

Consideration of the unparalleled discharge of overflow waters on June 13, as well as field observation of the excessive turbidity of the lake waters for several days after the flood flow, leads to the conclusion that a comparatively large proportion of the suspended silt was bypassed through the lake during this period. This subject is discussed further in the conclusions at the end of this report.

Summary

The detailed sedimentation survey of Hayes Lake revealed an average annual accumulation of 49 acre-feet of sediment, equivalent to about 20 cubic feet per acre of drainage area. If the average weight of the reservoir sediment is 41.7 and 32.7 pounds per cubic foot for the old and new deposits, respectively,[7] and that of the soil in the drainage area is 70.6 pounds per cubic foot,[8] the measured rate of sedimentation indicates that the time required to remove 1 inch of soil from the entire area is about 330 years. This is a relatively low rate of erosion, compared with many other areas on which similar studies have been made. However, there is some evidence that about as much sediment has been bypassed through the lake as has been deposited,[9] indicating that the above time should be reduced by one-half, or to about 165 years.

A complete summary of the results of the sedimentation survey is given in the following tabulation.

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[7]See footnote 4, page 16.

[8]Based on volume weights of samples of Colby silty clay loam and Houston black clay (which correspond approximately to the principal soil types of this area) given by Middleton, H. E., Slater, C. S., and Byers, H. G. The physical and chemical characteristics of the soils from the erosion experiment stations--second report. U. S. Dept. Agr. Tech. Bull. 430:21, 1934.

[9]See table 7 and discussion at the end of this report.

Summary of data on the sedimentation survey of Hayes Lake, Hayes, S. Dak.

Item	Quantity	Unit
Age[1]	4.2	Years
Watershed area[2]	40.0	Sq. miles
Reservoir:		
Area at crest stage:		
Original and at date of survey	88.1	Acres
Storage capacity to crest level:		
Original	629	Acre-feet
At date of survey	580	Acre-feet
Capacity per sq. mi. of drainage area:[2]		
Original	15.73	Acre-feet
At date of survey	14.50	Acre-feet
Sedimentation:		
Total sediment	49	Acre-feet
Old (prior to June 1937 flood)	33	Acre-feet
New (June 1937 flood deposit)	16	Acre-feet
Average annual accumulation:		
From entire drainage area	11.7	Acre-feet
Per 100 sq. mi. of drainage area[3]	29.3	Acre-feet
Per acre of drainage area:[3]		
By volume	19.92	Cubic feet
By weight[4]	0.39	Ton
Depletion of storage:		
Loss of original capacity:		
Per year	1.86	Percent
To date of survey	7.79	Percent

[1]Storage began March 1933; average date of survey, June 1937.

[2]Including lake area.

[3]Excluding lake area. This correction is of little significance in this case, as it is probably within the limit of accuracy of the watershed area.

[4]Using average weights of 41.7 and 32.7 pounds per cubic foot, respectively, for old and new sediment, as determined from samples. (See p. 11.)

STOCK PONDS

In this region of variable and low average rainfall it is an absolute necessity that the rancher conserve as much water as possible from each run-off to insure a supply for his cattle during the intervening dry periods of many days or even months. Especially is this true in Stanley and adjacent counties, for here the only other possible source of water is the artesian supply of the Dakota sandstone, which lies 1,800 to 2,000 feet below the surface. The "gouge holes" in intermittent streams afford watering places for some stock for a time after each rainfall, but their occurrence is too irregular and their capacity too limited to be equal to the needs. As a result of these circumstances stock ponds have been constructed on a large scale. Ten stock ponds, as shown in table 3, are at present in use in the Hayes Lake drainage basin.

Table 3.--Stock ponds in Hayes Lake drainage basin

Location number[1]	Name	Surface area	Storage Capacity	Drainage area
		Acres	Acre-feet	Acres
1......	Elkins No. 1...........	4.33	18.61	349
2......	Elkins No. 2...........	1.41	4.34	211
3......	Bergeson No. 1..........	3.21	12.20	4,160
4......	Bergeson No. 2..........	2.75	13.75	7,040
5......	Bergeson No. 3..........	3.67	20.19	1,600
6......	Headman No. 1...........	3.62	14.48	2,240
7......	Headman No. 2...........	2.75	16.50	640
8......	Headman No. 3...........	2.07	3.73	860
9......	Headman No. 4...........	2.64	15.84	1,440
10......	Headman No. 5...........	1.03	2.58	480
	Total................	27.48	122.22	19,020
	Hayes Lake...........	88.1	629.0	25,600

[1]For locations see figure 1 (following p. 1).

Relation of Stock Ponds to Hayes Lake

In view of the fact that the run-off from approximately 74 percent of the total drainage area reaches Hayes Lake only after passing through stock ponds, it is pertinent to evaluate their relative effectiveness as silt traps or desilting basins. Several facts are important:

(1) Although stock ponds in general may be considered relatively temporary features because of their susceptibility to dam failures during flood flows, the 10 existing ponds in this area have been operating during the entire life of Hayes Lake.

(2) All the ponds are characterized by a low storage capacity per unit of drainage area. This means that the ponds are relatively ineffective in slowing up the passage of water through them in flood flows, and thus afford relatively small opportunity for silt deposition. All the stock ponds, therefore, probably bypass a comparatively large proportion of the incoming silt load. Reconnaissance silt measurements in the stock ponds have shown that an average of less than one foot of sediment has accumulated in the basins.

(3) In many ponds that dry up periodically silt is removed by mechanical methods but is customarily used to increase the dam height and thus is removed from further transportation down the drainageway.

The results of detailed surveys of two representative stock ponds on the ranch of Milt Elkins (fig. 6) are given below:

Elkins Stock Pond No. 1

Location. SW$\frac{1}{4}$ sec. 21, T. 6 N., R. 26 E., Stanley County. Approximately 6$\frac{1}{2}$ miles north of Hayes, S. Dak., on a westward-flowing branch of Frozenman Creek (See fig. 1 (following p. 1), pond No. 1).

Ownership. Milt Elkins.

Purpose served. Water supply for range stock.

Description of dam and pond. The dam is an earth-fill gravity-type structure with an over-all length of 250 feet. The top of the dam is about 10 feet in width and is 16 feet above the stream channel. The spillway, 10 feet above the stream channel, is on the west side of the dam. It consists of a natural channel

which spreads overflow water on a gentle grade into the main valley about 100 feet below the dam. Both the upstream and downstream faces of the dam are on a 2:1 slope and the upstream face is protected from wave-wash by anchored baffle boards and by a scattered growth of willows.

The pond occupies an elongated and comparatively straight and narrow basin varied only by two minor tributaries which enter near the head of backwater. (See fig. 6.) It is about 1,200 feet long and narrows rather uniformly upstream from a maximum width of 250 feet near the dam.

Character of drainage basin. In general, the area above this stock pond is a miniature likeness of the total drainage area of Hayes Lake. The topography is gently rolling, with perhaps a greater proportion of level upland than the larger area as a whole. The proportion of cultivated land to range land is about the same. Of a total area of 297.52 acres, 51.88 acres, or 17.4 percent, are in cane, a cultivated crop. With respect to erosion conditions, however, some major differences appear. In the basin above the pond relatively little evidence of accelerated erosion exists. The cultivated area is fairly level and has not suffered the wind erosion noted in other cultivated fields in the Hayes Lake drainage basin. Little sheet erosion is in evidence and the slopes on the whole are not so steep and consequently have not eroded so severely as the valley walls downstream in the main drainage area.

The pond has been protected from excessive trampling, and the adjacent area does not show the overgrazing characteristic of some of the other stock ponds in the region.

Silting. Silt accumulation has been fairly uniform throughout the basin. The deposits have a maximum depth of 3 feet in the channel near the dam and gradually decrease in thickness away from the channel and toward the head of backwater. The silt which accumulated during the flood flow of June 1937 makes up more than 22 percent of the total volume of sediment. Here, as in Hayes Lake, there is a marked difference in compaction between the old and new sediment. Some of the old sediment has undergone alternate exposure and inundation and therefore has a considerably greater density, or weight per cubic foot.

The sediment differs but little from that in Hayes Lake. The old sediment, because of exposure, was somewhat difficult to differentiate from old soil or pre-lake material. This held true particularly in the shallow region, where repeated exposure had rendered the silt extremely compact. The results of the detailed survey of this pond are summarized in table 4.

Table 4.--Summary of data on Elkins stock ponds

Item	Elkins No. 1	Elkins No. 2
Age....................years..	1/ 28	2/ 26
Watershed area[3]..........square miles..	0.58	0.33
Reservoir:		
Area at crest stage:		
Original..............acres..	4.33	1.41
At date of survey..........do....	4.28	1.26
Storage capacity to crest level:		
Original..............acre-feet..	18.61	4.34
At date of survey..........do....	15.78	3.18
Capacity per square mile of drainage area:[3]		
Original..............acre-feet..	32.09	13.15
At date of survey..........do....	27.21	9.64
Sedimentation:		
Total sediment..............do....	2.83	1.16
Old (prior to June 1937 flood).......do....	2.20	0.50
New (after " " ").........do....	0.63	0.66
Average annual accumulation:		
From entire drainage area..........do....	0.10	0.04
Per acre of drainage area:[4]		
By volume..............cubic feet..	12.00	9.26
By weight[5]..............tons..	0.24	0.17
Depletion of storage:		
Loss of original capacity:		
Per year..............percent..	0.54	1.03
To date of survey..........do....	15.21	26.73

[1]Storage began May 1907; average date of survey, June 1937.
[2]Storage began May 1911; average date of survey, June 1937.
[3]Including pond area.
[4]Excluding pond area.
[5]Using average weights of 41.7 and 32.7 pounds per cubic foot, respectively, for old and new sediment, as determined from samples. (See p. 11.)

Elkins Stock Pond No. 2

Location. SW$\frac{1}{4}$ sec. 21, T. 6 N., R. 26 E., Stanley County. Approximately 6$\frac{1}{2}$ miles north of Hayes, S. Dak. (See fig. 1 (following p. 1), pond No. 1.)

Ownership. Milt Elkins.

Purpose served. Water supply for range stock.

Description of dam and pond. The dam is an earth-fill gravity-type structure 182 feet long and 11 feet in height above the channel bottom. It has a top width of about 5 feet and both the upstream and downstream faces are on a slope of 2:1. The dam extends nearly due north across a small tributary of the uppermost westward-flowing branch of Frozenman Creek. The spillway, with crest 6 feet above the channel bottom, consists of a shallow trench about 10 feet wide which conducts overflow water into a small arroyo that parallels the main branch and joins it below the dam. Although of limited capacity, this spillway has survived heavy discharges, owing in some measure to a grass cover in the bottom, and also to the gentle unbroken grade from the pond to the arroyo.

The pond is relatively wide and shallow; it narrows gradually from a width of about 200 feet at the dam to 30 feet near the head 500 feet above the dam, and has a maximum original depth of less than 8 feet (fig. 6).

Character of drainage basin. The area above this stock pond is one of the more actively cultivated sections of the Hayes drainage basin. It has a maximum relief of less than 50 feet and is characterized by long, gentle slopes. Very little level ground exists except along the divide. The cultivated areas, located on the gentle slopes, are subject to considerable sheet erosion which is locally of moderate intensity. The only other area in the basin where erosion is prominent is that part immediately adjacent to the stock pond, where overgrazing and trampling have damaged the vegetative cover and exposed the soil. Here numerous rills have been formed and fairly severe sheet erosion is in progress.

Silting. Delta accumulation has shortened the pond considerably, although the greatest thickness of silt in the delta is less than 0.5 foot. A maximum depth of 1.8 feet of sediment has accumulated in the deepest portion immediately above the dam, while the average depth of the silt is approximately 1.0 foot.

A surprisingly large proportion of the lake sediment, 57 percent of the total measured volume, consists of poorly compacted silt and clay deposited by the heavy run-off of June 12-13. This extraordinary relation, between the volume of silt deposited during one 48-hour period of heavy rainfall to that accumulated over a 26-year period during which a number of comparable rainfalls occurred, requires an explanation. For one thing, a marked difference in compaction exists between the two phases. In addition to natural compaction, the old silt has undergone considerable trampling by livestock and has been exposed over long periods when the pond was dry. Another factor, which is undoubtedly of the greatest importance, is the scouring to which pond sediment is subject during flood flows. Deposition of the large amount of silt attributed to the last flood flow no doubt occurred during the receding stages of the flood while comparatively little water was flowing over the spillway.

The sediment differs but little from that in Hayes Lake. As would be expected, the greater compaction due to exposure and to trampling by stock has rendered the distinction between old silt and pre-lake material less striking than in the main lake.

The results of the detailed survey of this pond are summarized in table 4 (p. 20).

CONCLUSIONS ON SEDIMENTATION RESULTING FROM THE FLOOD FLOW OF JUNE 12-13, 1937

In the absence of a detailed erosion survey of the area, a brief resume of the more important points, based on field observation, is given herewith:

Hayes Lake Drainage Basin

Erosion.--Moderate to severe, confined essentially to valley walls and cultivated areas. Steep valley walls along the lower 3 miles of the main stream are subject to slumping and sheet wash.

Average slope.--About 5 percent, except on steep valley walls.

Land use.--Cultivated areas, 15 percent of drainage basin, predominantly on the uplands, devoted to small grains and intensively cultivated crops; range land, 85 percent of drainage area.

Upstream deposits.--Extensive colluvial deposits and some scattered stream deposits.

Elkins No. 1 Drainage Basin

Erosion.--Very slight sheet erosion on cultivated areas.

Average slope.--About 3 percent.

Land use.--Cultivated areas, 17.4 percent of drainage basin confined to gentle slopes, devoted to small grains; range land, 82.6 percent.

Upstream deposits.--None.

Elkins No. 2 Drainage Basin

Erosion.--Slight to moderate sheet wash on cultivated areas; severe sheet erosion on one small area adjacent to the pond.

Average slope.--About 5 percent.

Land use.--Cultivated areas, 47.9 percent of drainage basin, generally on comparatively steep slopes, in small grains; range land 52.1 percent.

Upstream deposits.--Minor colluvial deposits only.

In order to compare the results of the several surveys, it is necessary to assume that rainfall intensity and amount were fairly uniform over the whole area during this two-day period. This assumption is supported by the fact that the various drainage basins are all confined to a limited area, and also by the official rainfall records for the several nearest Weather Bureau stations, which indicate that the rainfall under discussion was rather general. However, since areal variation in intensity and amount of rainfall for a given period is so characteristic of the Great Plains region, a further check on the rainfall in the Hayes drainage basin was undertaken. By contacting a representative number of the land owners in the area, records of local precipitation measurements in a number of open vessels were obtained. From these various records the actual rainfall during the period was determined to be approximately 1.50 inches on June 12 and 0.50 inch on June 13.

Field observations indicate that, with the sole exception of the eroding steep valley slopes near Hayes Lake, the cultivated fields furnished the major part of the erosional debris. There were four possible modes of disposal of this debris: (1) colluvial deposition at the foot of slopes from which the debris was derived, (2) deposition in (a) minor stream channels, (b) on the main stream flood plain, or (c) in upstream artificial ponds, (3) deposition in Hayes Lake, and (4) bypassing completely through Hayes Lake as suspended load during flood stages.

In the absence of more exact information on the intensity and time relationships of the two storms, it is impracticable to calculate the theoretical run-off by the "unit-graph" method. However, a minimum run-off figure can be derived on the basis of existing evidence. For example, there is fair evidence that the volume of flood water delivered to Elkins' Stock Pond No. 1 was equal to or somewhat greater than the volume of the basin itself. Since a run-off of 0.52 inch (26 percent of the precipitation) would deliver only a sufficient volume of flood water to fill this pond, a minimum figure of 0.60 inch of run-off (30 percent of the precipitation) seems a fair approximation of the true value. The actual run-off for the storm period may have been considerably higher.

If it is assumed that the above approximation is reasonably accurate, and if it is further assumed that the degree of run-off from the Elkins No. 1 drainage basin is representative of the entire Hayes Lake drainage area, the volume of run-off from any given area can be computed.

The following tabulation shows the volume of flood waters delivered to each of the basins during and after the storm, calculated on the basis of 30-percent run-off:

	Acre-feet
Hayes Lake	1,280
Elkins No. 1	18.6
Elkins No. 2	10.6

The run-off from each of the drainage areas was very "flashy", and a relatively high velocity of flow was maintained through the lake basins. The fact that a large amount of water, sufficient to fill each of the ponds several times, flowed through the basins in a very short period indicates that strong currents prevailed during the flood flow. It seems possible, therefore, that all but a minor

Table 5.--Summary of sedimentation in Hayes Lake and the two stock ponds resulting from the flood of June 1937

Reservoir	Initial capacity (1)	Sediment deposited (2)	Sediment load (Silt per acre-foot of inflow) Column (2) ÷ Column (1) (3)[1]	Total inflow (4)	Total incoming sediment Column (3) x Column (4) (5)	Sediment bypassed: Column (5) - Column (2) (6)	Sediment bypassed: Column (6) x 100 ÷ Column (5) (7)
	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Percent
Hayes............	596	15.65	0.03	1,280	33.6	18.0	53.5
Elkins No. 1.....	15.2	0.63	0.04	18.6	0.7	0.1	14.3
Elkins No. 2.....	3.8	0.66	0.17	10.6	1.8	1.1	61.1

[1] Computed on the assumption that the new sediment in each basin was deposited by a volume of inflow equal to the initial capacity.

fraction of the incoming sediment was bypassed during the actual flood flow, and that, therefore, the accumulated sediment represents deposition only during waning stages. In view of the extremely "flashy" nature of the flood, there is some basis for making a first approximation of the sediment load of the inflow in the following manner. On the assumption that deposition up to the time that water ceased to discharge over the spillway was negligible, the volume of sediment deposited represents the sediment load of a volume of water equal to the capacity of the individual basin. As the initial capacity of each basin and the volume of sediment deposited therein by the June 1937 flood are known, it is possible to compute the sediment load of the inflow in terms of volume of silt per unit volume of inflow, and from this, using the value for total inflow derived from a 30-percent run-off, to compute the total sediment load carried into each basin, including both the sediment deposited and the sediment bypassed. These data are presented in table 5.

The sediment output, in tons per acre of drainage area, may be computed by applying the dry weight of the sediment to the total volume of sediment load (table 6).

Table 6.--Computed sediment output of the Hayes Lake drainage basin resulting from the flood of June 1937.

Reservoir	Total sediment load per acre of drainage area	
	Cubic feet	Tons[1]
Hayes Lake	57.3	0.9
Elkins No. 1	85.7	1.4
Elkins No. 2	363.4	5.9

[1]Based on a dry weight of 32.7 pounds per cubic foot of silt, as determined from a sample of the flood deposit from Hayes Lake.

Since the data in table 6 take into account the bypassing of sediment load through the basins, but not the effect of upstream deposition, it is probable that a large part of the wide variation in calculated soil losses from the three areas can be attributed to differences in the drainage basins themselves.

A comparison of the percentages of cultivated land in the three basins with the calculated average soil losses per acre would seem to indicate a close relation between these two factors. However, consideration of the actual acreages of cultivated land does not support this apparent relationship. For example, the drainage basin of Elkins No. 2, with 101 acres of cultivated land, contributed more than $2\frac{1}{2}$ times as much sediment as that of Elkins No. 1, with only 61 cultivated acres. It seems probable that the steeper average slope prevailing in the cultivated area above Elkins No. 2 is a major factor affecting the amount of soil lost.

There is probably a closer correspondence between actual average soil loss and the computed sediment output from the smaller drainage areas than from that of Hayes Lake, because field observations indicated that upstream deposition was slight above Elkins No. 2 and practically absent above Elkins No. 1, compared with rather extensive deposition above Hayes Lake. Field evidence indicated that, on the average, cultivated areas in the larger area are subject to more severe erosion than the cultivated areas above either Elkins No. 1 or No. 2. Furthermore, the steep valley slopes near Hayes Lake, although very limited in areal extent, are subject to as much erosion as the cultivated areas. These points would seem to indicate a higher average net soil loss per acre in the larger drainage basin than in either of the minor basins. However, calculations reveal that the main drainage basin, with 63 times as much cultivated land, contributed only 46 times as much sediment during the June flood as that of Elkins No. 1. This difference is possibly due to upstream deposition of a large proportion of the soil actually moved from place in the area above Hayes Lake.

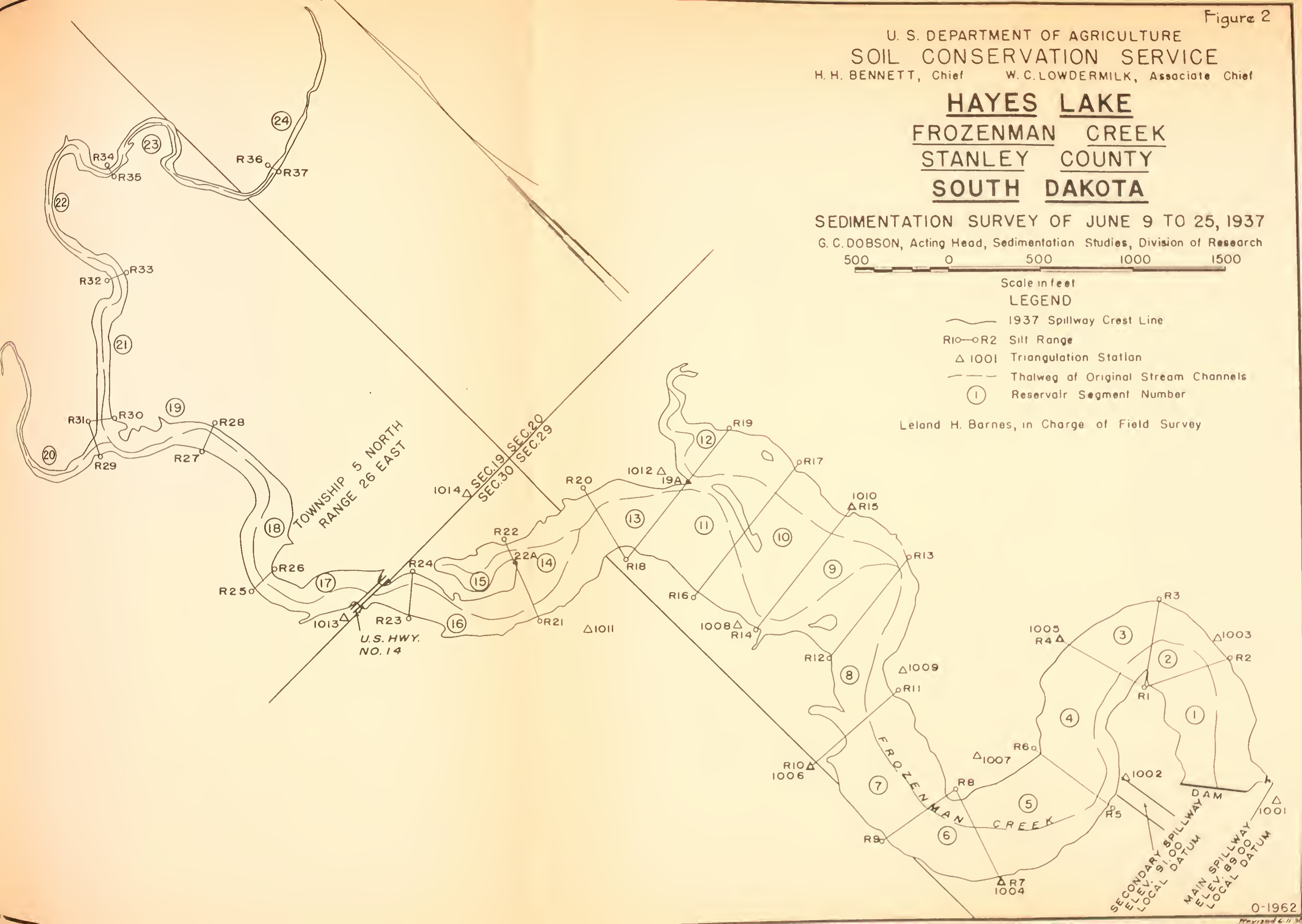
Since no appreciable upstream deposition occurred above Elkins No. 1 stock pond as a result of the storm of June 1937, it is evident that the soil loss per acre from this area is essentially the same as the sediment output per acre. Furthermore, since conditions above Elkins No. 1 are fairly representative of the entire drainage area, the average erosion rate in the smaller area may be taken to represent the larger area. By so doing it is possible to approximate the total volume of soil moved from place in the Hayes drainage basin, and also the volume deposited upstream from the reservoir (table 7).

Table 7.--Disposal of soil moved from place in the Hayes drainage basin by the flood of June 1937

Item	Volume	
	Acre-feet	Percent
Deposited in Hayes Lake..................	15.7	31.2
Bypassed through Hayes Lake..............	18.0	35.7
Deposited above Hayes Lake...............	16.7	33.1
Total soil moved from place.........	50.4	100.0

It would thus appear that the erosional debris from the Hayes drainage basin was almost equally divided between the three means of disposal, less than one-third being deposited in the reservoir.

Figure 2


U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
H. H. BENNETT, Chief W. C. LOWDERMILK, Associate Chief
HAYES LAKE
FROZENMAN CREEK
STANLEY COUNTY
SOUTH DAKOTA
SEDIMENTATION SURVEY OF JUNE 9 TO 25, 1937
G. C. DOBSON, Acting Head, Sedimentation Studies, Division of Research
500 0 500 1000 1500
Scale in feet
LEGEND
1937 Spillway Crest Line
R1—R2 Silt Range
△ 1001 Triangulation Station
Thalweg of Original Stream Channels
① Reservoir Segment Number
Leland H. Barnes, in Charge of Field Survey
TOWNSHIP 5 NORTH
RANGE 26 EAST
SEC.19 SEC.20
SEC.30 SEC.29
U.S. HWY. NO. 14
FROZENMAN CREEK
DAM
SECONDARY SPILLWAY ELEV. 91.00 LOCAL DATUM
MAIN SPILLWAY ELEV. 89.00 LOCAL DATUM
0-1962

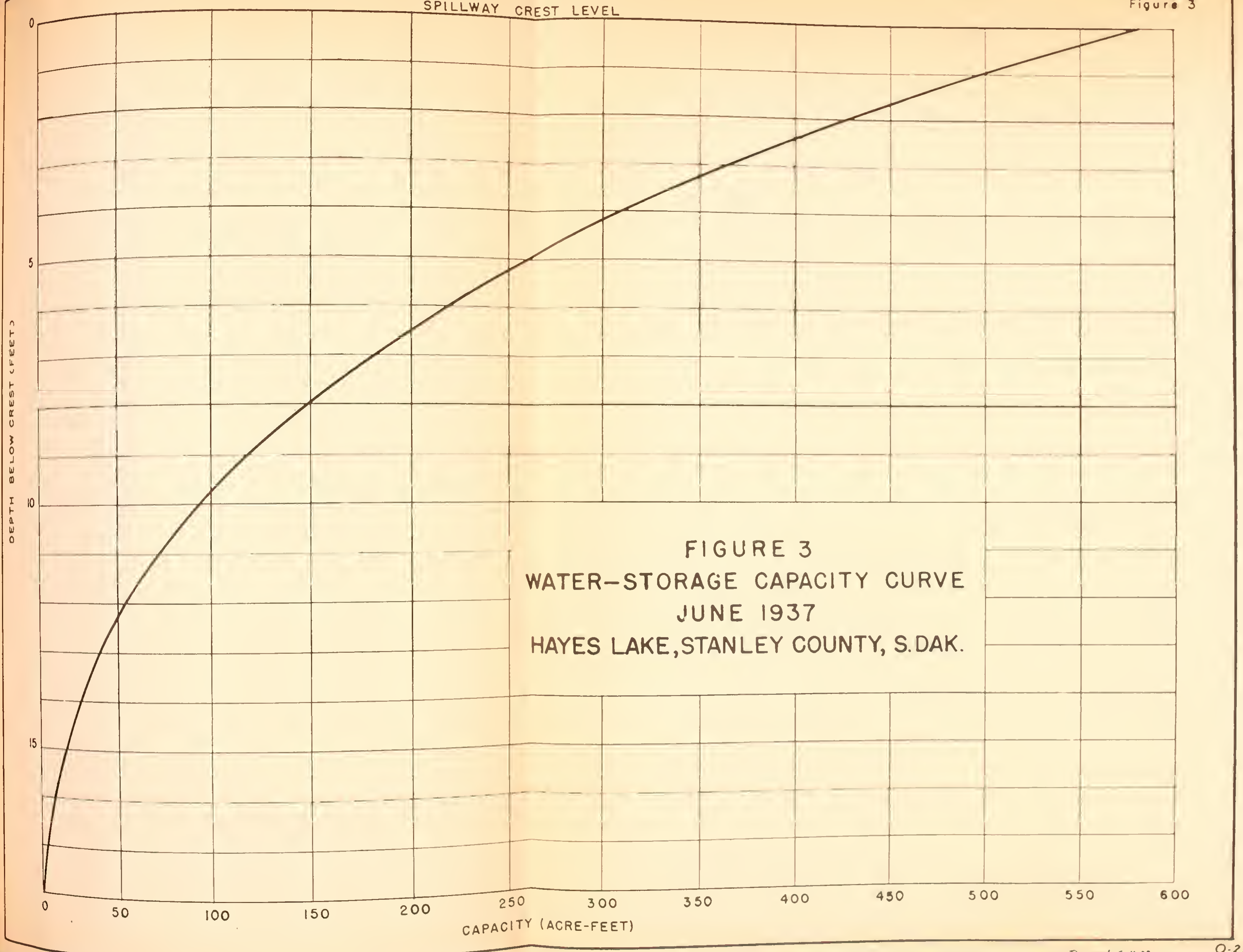


FIGURE 3
WATER–STORAGE CAPACITY CURVE
JUNE 1937
HAYES LAKE, STANLEY COUNTY, S. DAK.

Revised 6-11 38

O-222

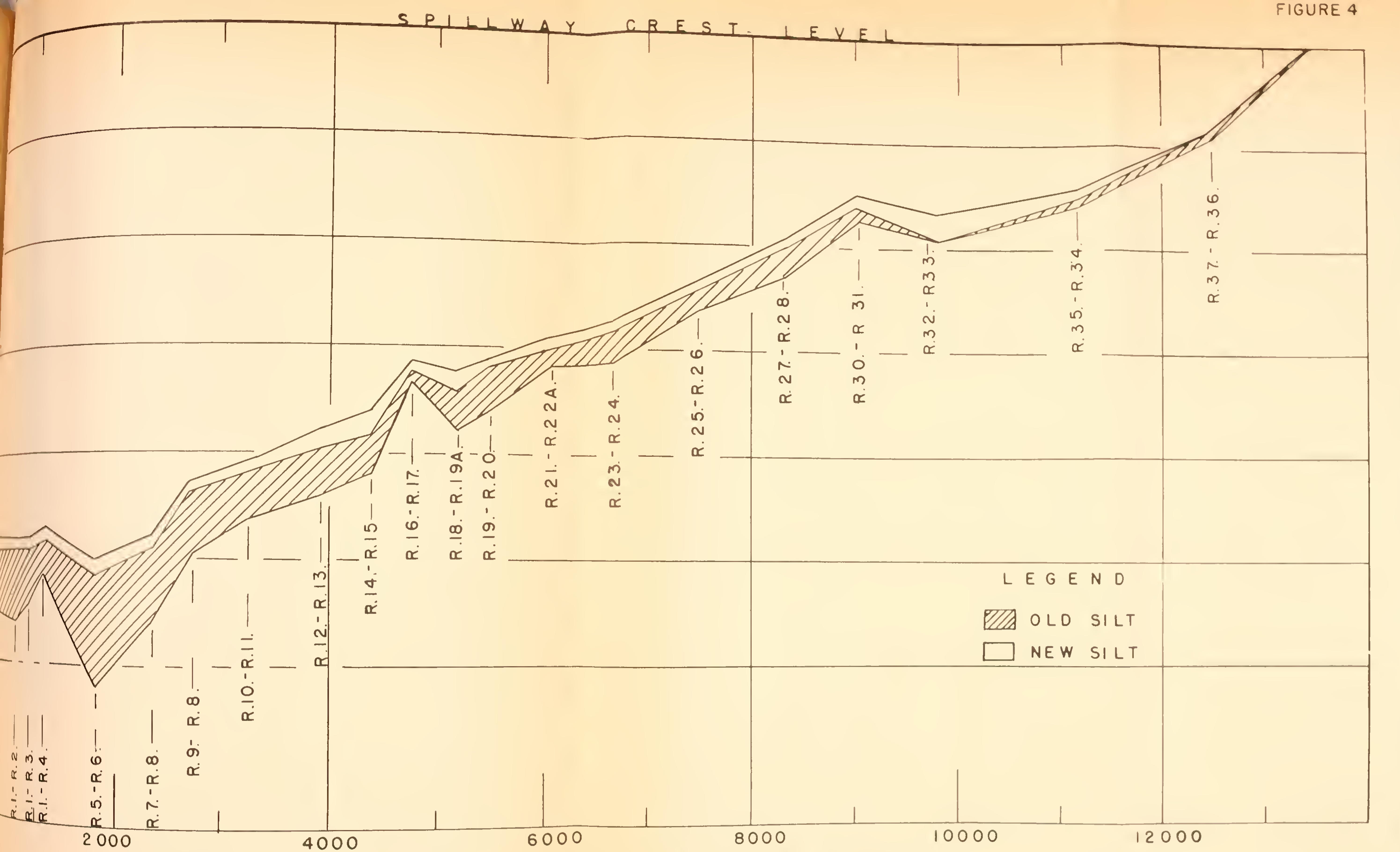


FIG. 4 MAXIMUM-DEPTH PROFILES OF HAYES LAKE
HAYES, SOUTH DAKOTA
JUNE 1937

Revised 6-11-38
0-2222

FIGURE 5

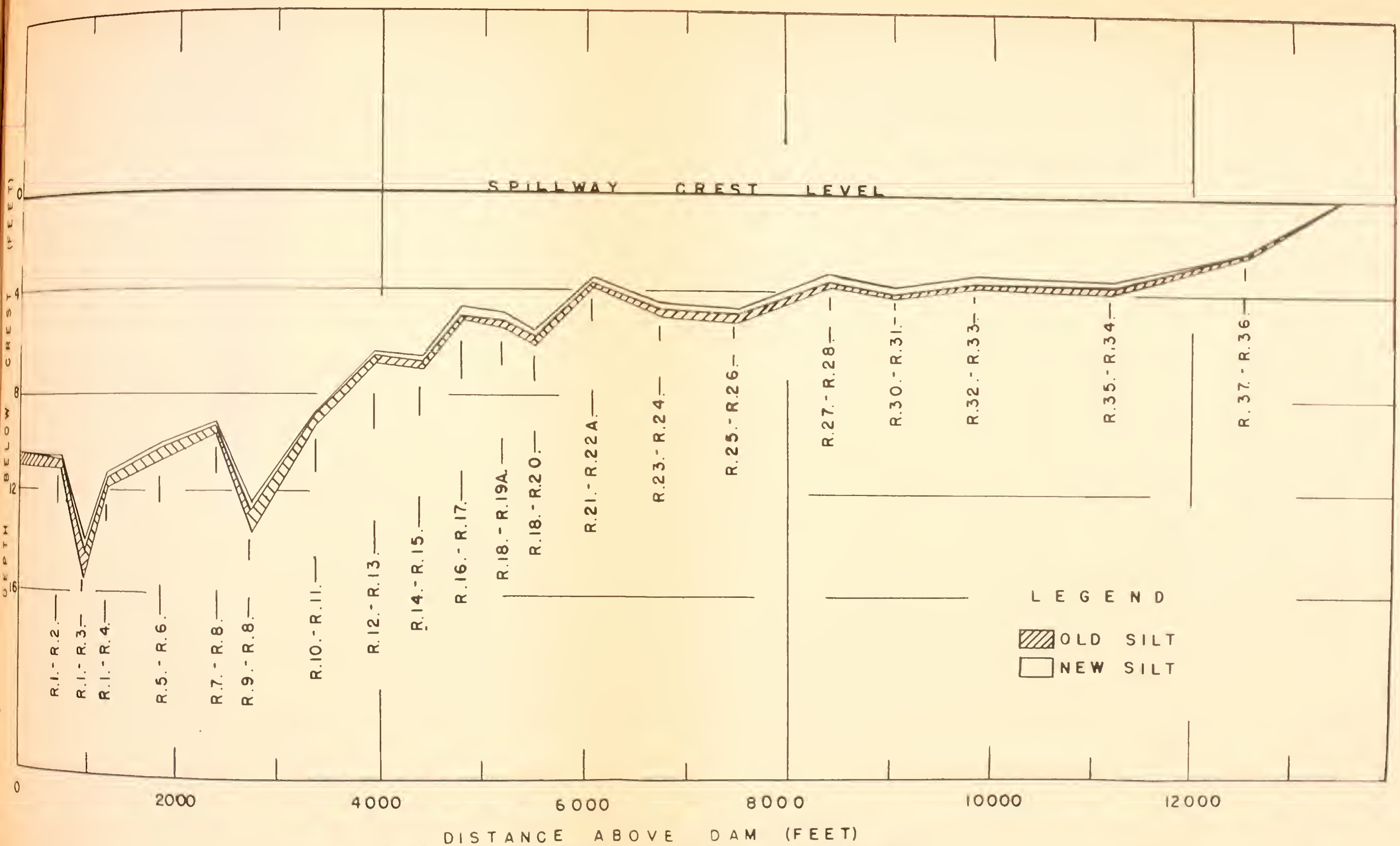
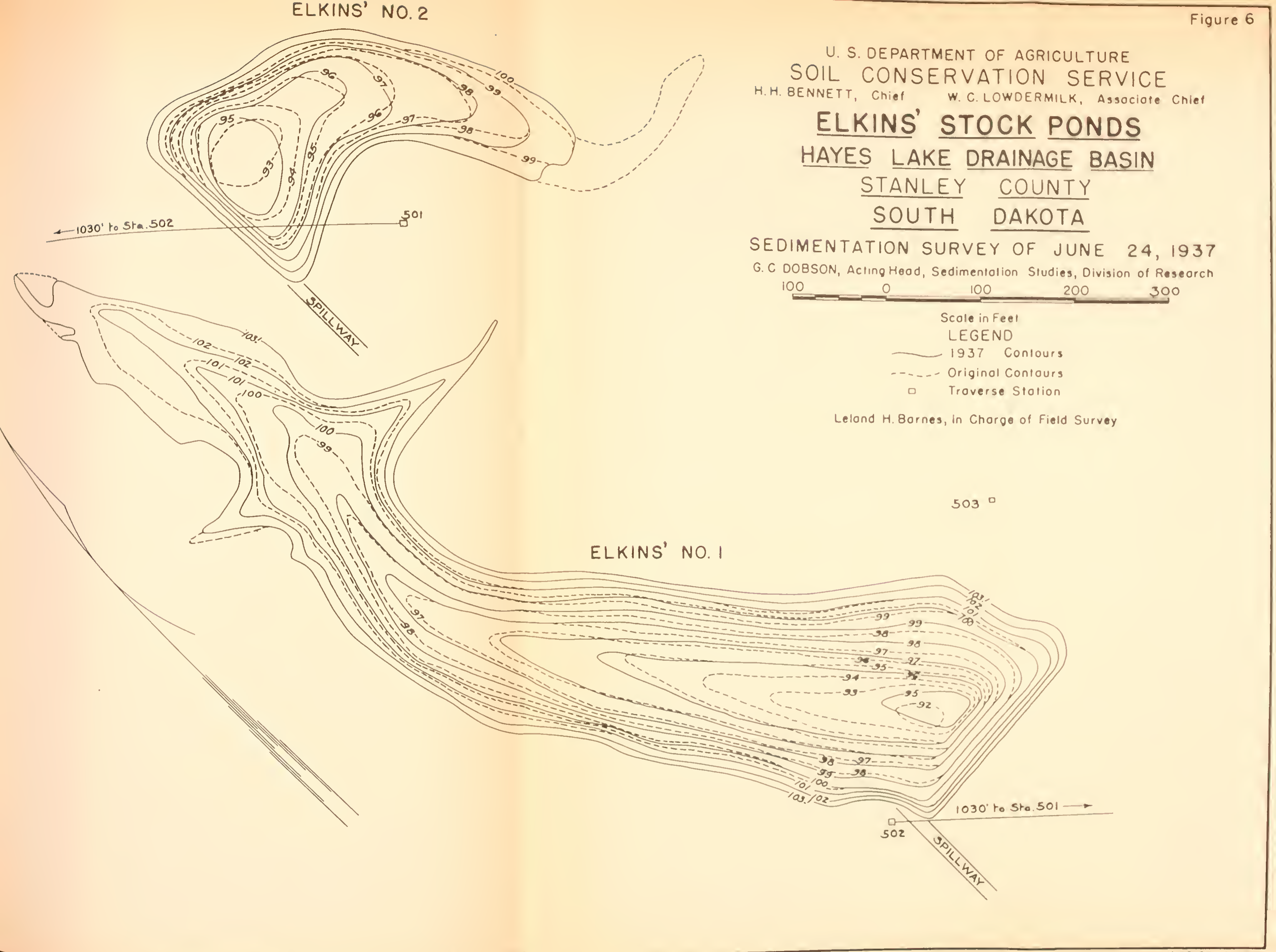


FIG. 5 AVERAGE-DEPTH PROFILES OF HAYES LAKE
HAYES, SOUTH DAKOTA
JUNE 1937

Revised 6-11-38 O-2223

Figure 6



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